Intrusion Detection Using Passive Infrared Sensor (PIR)

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Abstract: Pyroelectric Infrared (PIR) sensors are widely used as a simple presence trigger for alarms and a reliable counter for people in security home and smart office. Most paper have focused on the design and application of such systems, however, few research has been done on the detecting of targets in an outdoor environment using PIR sensors. In this paper, we realize a detecting system by means of PIR nodes to monitor outdoor targets more than 20 meters away from the PIR detectors. Furthermore, because of velocity difference, by extracting time domain amplitude, signal length, maximum frequency and corresponding frequency amplitude as features, we successfully classify people, wheeled vehicle and tracked vehicle in the unattended wild ground environment. Our detecting and classifying results confirm the average accuracy is 85.67% and 82.67% when PIR detectors are deployed 20 meters and 30 meters away from the area of interest (AoI), respectively.

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INTRODUCTION
Pyroelectric Infrared (PIR) sensors are made of pyroelectric materials which can produce an electric potential by means of a very small change in temperature. The heat variation of a human or animal from several feet away is enough to generate a difference in charge. Hence, PIR sensors are quite fit for detecting moving targets. PIR sensors are largely accepted in indoor security systems for its low-cost, low-power, reliable performance and convenient operation. Beyond these characteristics, it provides accurate information for target presence and even the number of targets. Nowadays, many security systems have made PIR sensors to be a good alarm of intrusion [1] and a precise counter for targets who are not only people [2] but also vehicles [3, 4] and so on. However, previous works mostly concentrate on detecting while we use PIR sensors to classify targets after detecting. Moreover, our PIR nodes are not deployed in an indoor environment where the detecting range is confined in several meters. They are used to detect targets more than 20 meters away in an unattended wild ground environment.

In this paper, we design a detecting system to monitor a specific wild district using PIR sensors. Targets such as people, wheeled vehicle and tracked vehicle from more than 20 meters away are to be detected and classified by means of PIR nodes. Simulation results show that the accuracy is unsatisfied and thus proved that PIR nodes can be used in an outdoor environment such as state border and battlefield. The rest of the paper is organized as follows. In Section III, we introduce the structure of PIR detectors and nodes. Our method for detecting, counting and classifying is presented in Section IV and V. Finally, we give the experimental results and conclude the paper in Section VI and VII.

LITERATURE REVIEW
PIR detectors are widely used in people presence detecting systems. In [2], PIR detectors instead of camera sensors are installed over the stairs in the building to count the passersby. By using pattern recognition methods, the detecting accuracy of moving direction can be 99% and then the number of passersby is 95%. Paper [1] describes a simple intruder detection system based on PIR detectors which are installed on the wall of a protected room. Entering into this monitored area will cause the processor to produce an alarm signal and send it to the control center. Zappi et al. in [5] proposed a novel configuration and use of PIR sensors. They use three detectors located along a wall of a hallway to extract people’s movement features with 100% correct of direction recognition and 89% accuracy of people counter. As the research of PIR sensors goes deeply, more attentions are focused on target localization and tracking application. For example, the author in [6] proposed a smart system by deploying an array of PIR sensors on the ceiling of a room to locate a moving resident and at the same time record the trajectory. Furthermore, they developed a resident location-recognition algorithm using a Bayesian classifier to increase the accuracy [7]. Similarly, four sensor modules, each consisted of five PIR detectors, are mounted on the ceiling of a monitor field to fix the position of a moving human target [8]. In

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addition, Kalman filter is adopted to improve the tracking accuracy. To achieve higher accuracy, reference [9] combines PIR monitoring system with RF localization module to get the target position at a mean square error of less than 1m. Paper [20] proposes an infrared object localization and tracking system using wireless pyroelectric sensor networks. In recent years, more work concerned with recognition and classification utilizing PIR sensors has been done. For example, awireless pyroelectric sensor system is presented to recognize different walkers’ gait features [10]. Kaushik and Branko [11] have investigated the characteristics and spatial sensitivity of PIR Detector through experiments. Finding that the detector output has an evident relationship with the velocity and vertical distance of movements, they pointed out that a PIR system can be used to monitor the occupancy pattern of elderly people. In [12], 40 infrared sensors are installed at doors, gateways of the laboratory to extract individual human behaviors from long-term data. Paper [13, 14] has developed a PIR system to classify target distance from sensors into three groups: close, middle and far by extracting signal output amplitude and duration as features. Classifiers including Naive Bayes, Support Vector Machines and k-Nearest Neighbor (k-NN) are applied on those features to achieve a correct ratio ranging from 83.49% to 95.35%. These applications mentioned above [1, 2, 5-14] have illustrated how the research with regard to PIR goes deeply. However, all of these systems have placed PIR detector in an indoor environment less than 10m×10m. Thus it limits PIR sensors to be deployed at a hall or in a room where a certain security and smart system is constructed. But the detecting range of a PIR detector can be up to more than 20m, which makes it possible to be used at a highway intersection or a distant wild path. Hence, we creatively use PIR detectors in an outdoor environment to extend their scope. On the other hand, the literature demonstrates that PIR sensors are able to extract kinds of features and accordingly to distinguish people’s behavior, gait, position, distance and etc. However, PIR sensors are not patent for human detection but also other targets such as vehicles [3, 4]. Therefore it is natural to use PIR sensors to detect multitarget and classify them. For instance, they can be used to classify military vehicles instead of acoustic sensors that are sensitive to wind noise [15]. In this paper, a novel application is proposed that PIR detectors are utilized to classify individuals, wheeled vehicles and tracked vehicles more than 20 meters away in a wild environment. Through our analysis and experimental results, it is proved that targets such as vehicles can also be detected and counted. Besides, these three targets are able to be classified to some extent.

**METHODOLOGY**

**Pir Detectors and Nodes**

Pyroelectricity is the ability of certain materials to generate a temporary voltage when they are heated or cooled [16]. When a pyroelectric element senses an incident IR flux, it first converts the radiation flux change into a temperature change and then performs a thermal change to be a temporary voltage. Generally, a window equipped with a light filter is set on the top of the pyroelectric sensor to filter infrared light of specific wavelength. Thus only human IR radiation is absorbed if the light filter constrains the passing wavelengths to be human body infrared wavelength region. This kind of sensor is specially designed to detect people presence.
Figure 2 gives out the block diagram of PIR nodes. As we can see, a PIR node is mainly made up of a PIR detector, a signal processing unit and a communication unit. The PIR detector belongs to the class of passive sensor being low-power but reliable. The signal processing part consisting of a filtering and amplifying module, an ADC module and a microcontroller module is the most complicated. In order to reduce power consumption, we can choose low-power devices such as Texas Instruments’ ultralow-power microcontroller MSP430 series whose current is only 1.2uA when in standby mode [17]. However, low-power microcontroller is often at the price of low computational complexity and little memory space. Hence, it is not appropriate to use too complex algorithm on such processor. In later section we will present how to deal with the PIR signal as simple as we can. The communication unit includes a RF module and an antenna. In most cases, wireless transmitting and receiving is rather energy-consuming compared to a microprocessor. Usually there is a compromise between signal processing and wireless communication because more signal processing such as aggregation and fusion will get a simpler result which requires less communication burden, and vice versa. In our system most of the signal analytic task is placed on the node locally as the wireless module needs relatively high transmit power to support a far transmission distance to the remote receiver. Considering the excellent performance of microcontroller, it is rational and worthwhile to make processor more hardworking.

Figure 3 demonstrates how we use IR nodes to detect an area of interest. PIR nodes are placed tens of meters away from the AOI. When targets such as people and vehicles enter into the FoV of a specific PIR node, the microcontroller processes the detector output to judge the direction and furthermore extract several target features. Then the controller sends targets’ information including direction, number and feature vector to the remote receiver through wireless module. The remote receiver will classify the targets respectively according to each feature vector. If necessary, the results will report to the user to help make a decision. During this process, the detecting algorithm and classifying ability are the most critical, as will be discussed next.

DETECTING ALGORITHM
A PIR detector with a single Fresnel lens and a sensor of two inverse sensitive elements produces an output as shown in Figure 4 while a person moves through the detector and turns back. Generally speaking, this is a typical output signal for all kinds of targets. Since a target enters into the FoV, the dual sensitive elements with opposite polarity response the change one after another, thereby producing a positive peak and a negative peak. We can easily process such a signal only in the time domain and achieve a reliable detecting result. As described in Figure 4, the output is divided into noise and useful signal by two amplitude thresholds. The former is incompletely located between the positive threshold AP and the negative threshold An while the latter starts when one of the thresholds is crossed and ends when another threshold is crossed followed a stable period. This duration is called settle down time T that indicates the ending of last target and enables the following detection. It is clearly stated in paper [14] that there is a tradeoff between amplitude threshold and settle down time threshold. A high amplitude threshold may cause a potential distant target incapable of being detected. However, a low threshold brings a longer settle down time which makes two close targets unable to be distinguished. Hence, proper thresholds and settle down time are always determined by concrete applications. In our tests, by computing the mean value of noise, denoted as Am, we fix the threshold AP and Am ±400, respectively. Meanwhile, T is chosen to be 0.8 sec.

It is easily discovered from Figure 4 that the two different peaks of a real signal represent the direction of a moving target. Reaching the positive threshold firstly indicates that the object is moving from one side to another. On the contrary, firstly grabbing the negative threshold means the object is moving in an opposite direction. This direction identification task is just a piece of cake for any microprocessor.

Based on our detecting algorithm as shown in Figure 4, two time domain features are extracted from a PIR signal. The first is the signal amplitude. Different targets have different temperature and radiation property, thus making the output amplitude variable. The second is the signal length. Due to different volumes and distances of targets, the output signals have different lengths of duration. In fact, paper [13, 14] has successfully chosen signal amplitude and length as features to classify targets’ distance away from the sensor into three ranges. However, only these two features are not enough to classify different targets. In the next section, we will show how...
to classify different types of targets by combining the two time domain features with other frequency domain features.

**TARGET CLASSIFICATION**

In [11], it is found that the PIR detector output voltage is relational to the velocity of movements. These achievements reveal that the output of IR detectors does not only demonstrate the presence and direction of moving targets but also reflects certain targets’ attribute information such as distance, category, velocity, etc. Previous works mostly concentrate on the former while this paper will discuss the latter thoroughly. Although literature [11, 14] has carefully examined the output characteristics of IR signal in the time domain, it is just based on the empirical observation and test which lacks of strictly theoretical analysis. In fact, the IR output signal depends on such aspects [18]:

1. Distance of human body to the motion sensor
2. Walking speed of human body
3. Focal length and pattern design of the optical system

Here, we can replace human body with other targets if an appropriate light filter system is designed to let other targets’ IR radiation absorb. Once the Fresnel lens is determined, the optical system is then fixed and has negligible influence on the output of different targets. Hence, the distance and speed are the major factors to decide the output. Specifically, these two mainly change the signal amplitude defined by the difference between positive and negative peaks and the signal length being the time interval between entry point and end point (see Figure 4). Thus in paper [14], the author chooses signal amplitude and length as features to distinguish different distances for a fixed speed target. However, it is incapable of classifying various types of target at different speed within different distance. To solve this problem, we have to take frequency information of IR output into consideration. Paper [18] points out that a very good rule of thumb can be the use of the formula below for the relation between velocity, focus and frequency:

\[ f = \frac{v \times f_1}{2\pi \times s \times L} \]

**Figure 5. Output frequency as a function of distance \( L \) and velocity \( v \).**

For a specific practical detecting system, \( b \), \( f_1 \) and \( s \) are constants. Therefore, \( f \) is decided by \( b \) and \( L \). Figure 5 gives out an intuitive explanation for the relationship between output frequency, velocity, and distance. Here we choose \( b f_1 = 25mm \) and \( s = 1mm \). It can be seen that the output frequency is a function of velocity and distance. Either of them is constant, the output is changing followed the other. As stated in last paragraph, target distance can be distinguished by timedomain features. Hence, from the point of principle, targets with different speed and different distance can be classified depending on the output frequency. However, in our application, the detecting range is fixed once the detector is installed. Thus velocity difference of targets is a sole proof to recognize targets. If the output frequency differs from each other, then the velocity representing different targets is also different. Figure 6 illustrates a map of output signal and the corresponding frequency. Figure 6(c) is the frequency output of the signal in Figure 6(a) when a person being 20 meters away walks and runs across the sensor at a speed of 1m/s and 2m/s, respectively. It indeed shows that fast movements result in high frequency output. At the same time, the signal length of walking is longer than that of running as shown in Figure 6(a). This is because slower movements would bring longer existing time in the fixed FoV of the sensor at a fixed distance. It can also be seen from Figure 6(b) that different velocity leads to unequal signal duration. Figure 6(d) is the amplitude spectrum of Figure 6(b). From this figure, we conclude that wheeled vehicles have the highest main frequency component while people have the lowest main frequency component due to different moving speed. In fact, we sampled the signal in Figure 6(b) at 30 meters away at 1m/s, 8m/s and 10m/s for people, tracked vehicle and wheeled vehicle respectively. In general, using frequency information to recognize targets with different speed is feasible.

Based on the above analysis, we extract two frequency domain features: main frequency component and its corresponding amplitude. As shown in Figure 3(c,d), A, B, C, D and E are the extracted feature points. In order to classify human and vehicles, time domain features have to be used to distinguish distances. In addition, frequency domain features must be extracted to recognize different moving speeds of human and
vehicles. Therefore, frequency domain features and time domain features are combined to form a feature vector as follows:

$$V = \left[ S_{amp}, L_s, F_{auxsens}, f \right]$$

Using this 4-D vector, it is capable of recognizing different targets at different speeds. Next section will prove the feasibility and success of our target classification method.

CONCLUSION

This paper proposes the possibility to use PIR nodes to classify targets. By making use of a single PIR node, we can not only detect and count targets being several tens of meters away, but also can distinguish different targets by extracting features from both time domain and frequency domain. Simulation results show that the average accuracy can be up to 84.17%. Our research has liberated PIR detector from applications of alarm and surveillance. It is believed that PIR detectors are not only qualified to detect, but also to classify. In addition, they are quite appropriate to be largely employed in unattended ground sensor network (UGSN) systems which are principally implemented in battlefield and state border. In the future, we will continue to improve the classifying accuracy and try to recognize more kinds of target.

Resource Requirements

Computer/laptop with below mentioned configurations are required.

Hardware Requirements

Hardware needed to connect the chip & system: programming Kit (IC chip burner to program microcontroller) AT commands to drive GSM modem.

Software Requirements

Compiler: KeilMicrovision software
Bootloader: Burning tool or Burning software
Protocol Design: C

REFERENCES